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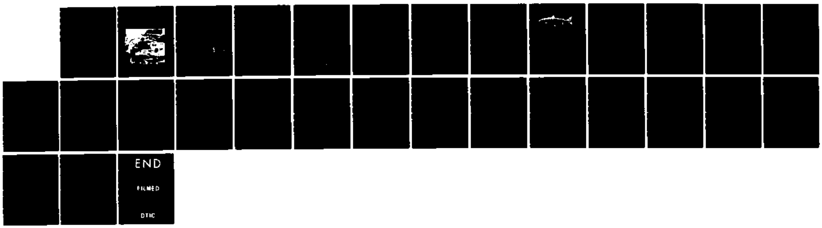

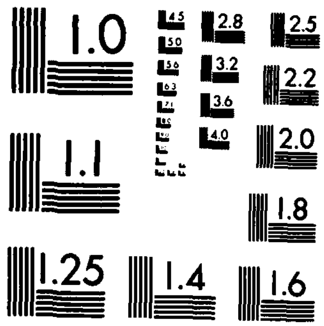

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic)

ATLANTIC SALMON

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

Fish and Wildlife Service
U.S. Department of the Interior

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ATLANTIC SALMON

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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to:

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CONTENTS

	Page
PREFACE	iii
CONVERSION TABLE	v
ACKNOWLEDGMENTS	vi
NOMENCLATURE/TAXONOMY/RANGE	1
MORPHOLOGY/IDENTIFICATION AIDS	2
REASON FOR INCLUSION IN SERIES	3
LIFE HISTORY	3
Spawning	3
Fecundity and Eggs	3
Larvae and Juveniles	5
Smolts and Sea Migrants	6
Sea Life and Homeward Migration	6
GROWTH CHARACTERISTICS	7
COMMERCIAL/SPORT FISHERIES	9
ECOLOGICAL ROLE	11
Food Habits	11
Predation	11
ENVIRONMENTAL REQUIREMENTS	12
Temperature	12
Dissolved Oxygen	12
pH	12
Depth and Velocity	13
Light	13
Salinity	14
Substrate, Sediment, Turbidity	14
LITERATURE CITED	15

CONVERSION FACTORS

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees	1.8(C°) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
British thermal unit (BTU)	0.2520	kilocalories
Fahrenheit degrees	0.5556(F° - 32)	Celsius degrees

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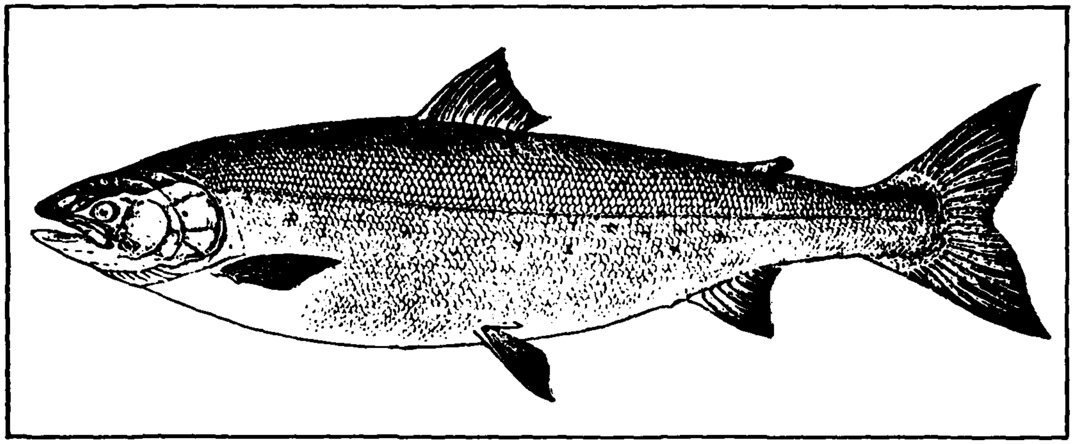

Figure 1. Adult Atlantic salmon.

ATLANTIC SALMON

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . . . . .*Salmo salar*
Common name . . . . . Atlantic salmon
Other common names . . . . Ouananiche, Kennebec salmon, landlocked salmon, Sebago salmon. French common names: Saumon atlantic, saumon d'eau douce, bratan
Life stage names . . . . Parr (freshwater juvenile), smolt (juvenile migrating to sea), grilse (Figure 1) (adult returning to freshwater to spawn after 1 year at sea), bright salmon (adult returning after 2 or more years), kelt or black salmon (a postspawning or spent adult) (Allen and Ritter 1977).
Class . . . . Osteichthyes
Order . . . . Clupeiformes
Family . . . . Salmonidae

Geographic range: The Atlantic salmon is indigenous to the North Atlantic Ocean basin (Figure 2). Their range in the eastern Atlantic extends from the Arctic Ocean to Portugal, including the Baltic Sea. In the western Atlantic, they range from Iceland, southern Greenland and Ungava Bay, Quebec, to the Connecticut River (Scott and Crossman 1973).

Anadromous Atlantic salmon once inhabited North American streams along the Atlantic coast, perhaps as far south as the Hudson River, New York, and the St. Lawrence River tributaries including Lake Champlain and Lake Ontario. Anadromous populations are now restricted to rivers from Connecticut northward to Ungava Bay, Quebec, and in Labrador as far north as the Fraser River, Nain Bay. In Greenland they inhabit the Kapisigdlit River at the head of Godthab Fjord northward from Kap Farvel to Umanak on the west coast and to Angmagssalik on the east coast (McCrimmon and Gots 1979). Attempts to restore anadromous populations to the Connecticut, Merrimack, Penobscot Union and Pawcatuck Rivers in New England, primarily by stocking hatchery-raised parr

and smolts, have been partially successful. The range of landlocked populations in Maine, New Brunswick, and Nova Scotia has been extended. In Maine, for example, landlocked Atlantic salmon endemic to only four watersheds, have been transplanted to hundreds of lakes.

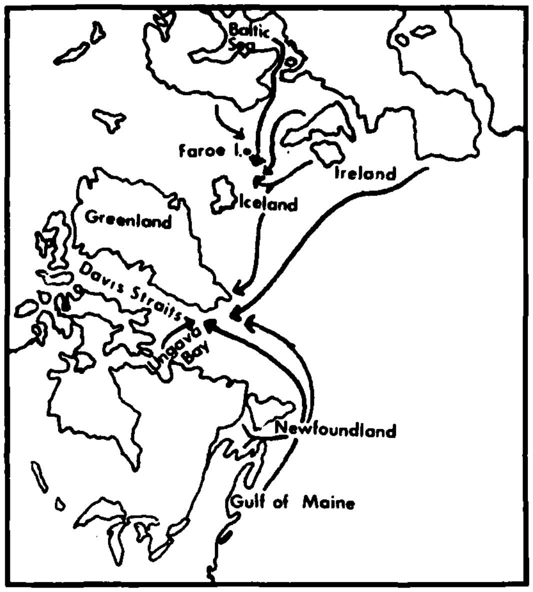

Figure 2. Worldwide range of Atlantic salmon and migratory routes (Netboy 1974).

MORPHOLOGY/IDENTIFICATION AIDS

Body elongate, somewhat compressed laterally, greatest body depth at dorsal fin origin or slightly posterior to dorsal fin, 18% to 22% of the total length. Head length about equal to or slightly greater than body depth, 20% to 23% of the total length, but most variable during modifications of head structure during spawning. Eye moderate, 14% to 19% of head length (variable depending on growth rate); snout rounded, its length greater than eye diameter for fish over 305 mm long; mouth terminal, large, maxillary extending posteriorly to posterior margin of pupil when 152 mm long, and seldom to posterior margin of eye except on mature males, which develop a pronounced hook or kype on lower jaw. Well-developed teeth on upper and lower jaws (premaxillary, maxillary, dentary); few teeth in a single row on shaft of vomer and palatines, on tongue in two rows; no hyoid teeth. Total gill raker count, 15-20. Branchiostegal rays usually 11-12 (rarely 10 or 13). Fins: adipose present posterior to dorsal, dorsal, 10-12; anal, 8-11; ventral, 9-10, with a distinct pelvic axillary process; pectoral, 14-15. Caudal with shallow fork. Scales cycloid, 109-121 in lateral line, 10-13 from posterior edge of adipose base to lateral line; lateral line decurved anteriorly, straight posteriorly. Pyloric caeca, 40-74. Vertebrae, 58-61 (Scott and Crossman 1973).

Pigmentation: Color varies with age, environment, and life stage. Small parr have 8 to 11 pigmented bars alternating with a single row of red spots along the lateral line on each side. Migrating smolts and adults at sea are silvery on the sides and belly, but the adults have brown, green, or blue coloration on the back and numerous black spots, usually x-shaped, scattered along the body, more numerous above the lateral line. A few of these spots are also located on the head. Landlocked adults have more numerous and larger spots than anadromous salmon (called bright salmon when first entering fresh water). At spawning, pectoral and caudal fins become blackish and both sexes take on a bronze to purple coloration and may acquire reddish spots on the head and body. After spawning, the surviving adults (kelts) are dark colored.

Distinctions: Dark spots on a light background distinguish Atlantic salmon from light spotted chars (brook trout and Arctic char), which have light spots on a dark background (Leim and Scott 1966). Atlantic salmon also

have larger scales, and have teeth on the shaft of the vomer. They may be distinguished from rainbow trout by the absence of serial rows of black spots on caudal fin and from brown trout by the shorter maxillary, narrower peduncle, lack of red on the adipose, and larger scales. Species of introduced Pacific salmon are distinguished by the larger number of anal fin rays, 12-19, whereas the Atlantic salmon has 8-11.

REASON FOR INCLUSION IN SERIES

The anadromous Atlantic salmon has high social and economic value because of its mystique as a sport fish and the high quality of its flesh. Once relatively widespread, this species is now restricted to several rivers of New England (Figure 3), where dams, pollution, and fishing have excessively reduced reproductive potential. During the egg, larval, and parr stages, this salmon is especially vulnerable to the consequences of coastal development projects; therefore knowledge of the life history and environmental requirements of this species is essential for decisions that will assure its continued existence and enhancement.

LIFE HISTORY

Spawning

Atlantic salmon spawn during the period of mid-October to mid-November in gravel areas of freshwater streams (Bigelow and Schroeder 1953). Spawning sites are located at the downstream end of the riffles with water percolation through the gravel or at upwellings of groundwater. Redds are constructed by the female using her caudal fin in a fanning motion. A redd consists of several depressions or pits excavated from the stream bottom (Leim and Scott 1966). Water temperatures during spawning usually range between 4.4° and 5.6°C (DeCola 1970). The male aligns himself with the female and fertilizes the eggs as they are deposited into each pit (Jordan and Beland 1981). Some male parr become sexually mature and take an active part in fertilizing eggs. The female then covers the eggs with about 10-25 cm of the gravel excavated while building another pit just upstream. This process is repeated until spawning is completed.

Fecundity and Eggs

Fecundity depends largely on body size. For example, anadromous Atlantic salmon produce more eggs than the landlocked form because its females are larger. A rule of thumb is that anadromous females produce 1,500 to 1,800 eggs/kg. Rounsefell (1957) reported that females weighing about 5 kg produced about 1,800 eggs/kg. Pope et al. (1961) used the following formula (modified by Baum and Meister 1971) to estimate the number of eggs produced by fish with different body lengths:

$$\mathrm{Log}_{10}N = 2.69 \log_{10}L - 0.15$$

Eggs are spherical, 5-7 mm in diameter, and pale orange or amber. The eggs are slightly adhesive initially and stick to the substrate in the pit until they are covered with gravel. The incubation period varies with stream temperature. In Maine the eggs hatch in April or early May after 175 to 195 days under normal winter conditions (Jordan and Beland 1981). An incubation of 110 days at 3.9°C cited by Leim and Scott (1966) probably is for hatchery eggs.

Egg size is influenced by the age, size, and physiological condition of the female. Egg size is also determined by the length of time the female lives in the ocean, the time of spawning, and the position of the egg in the ovaries. Average egg weight is 164 mg. The rate of embryo develop-

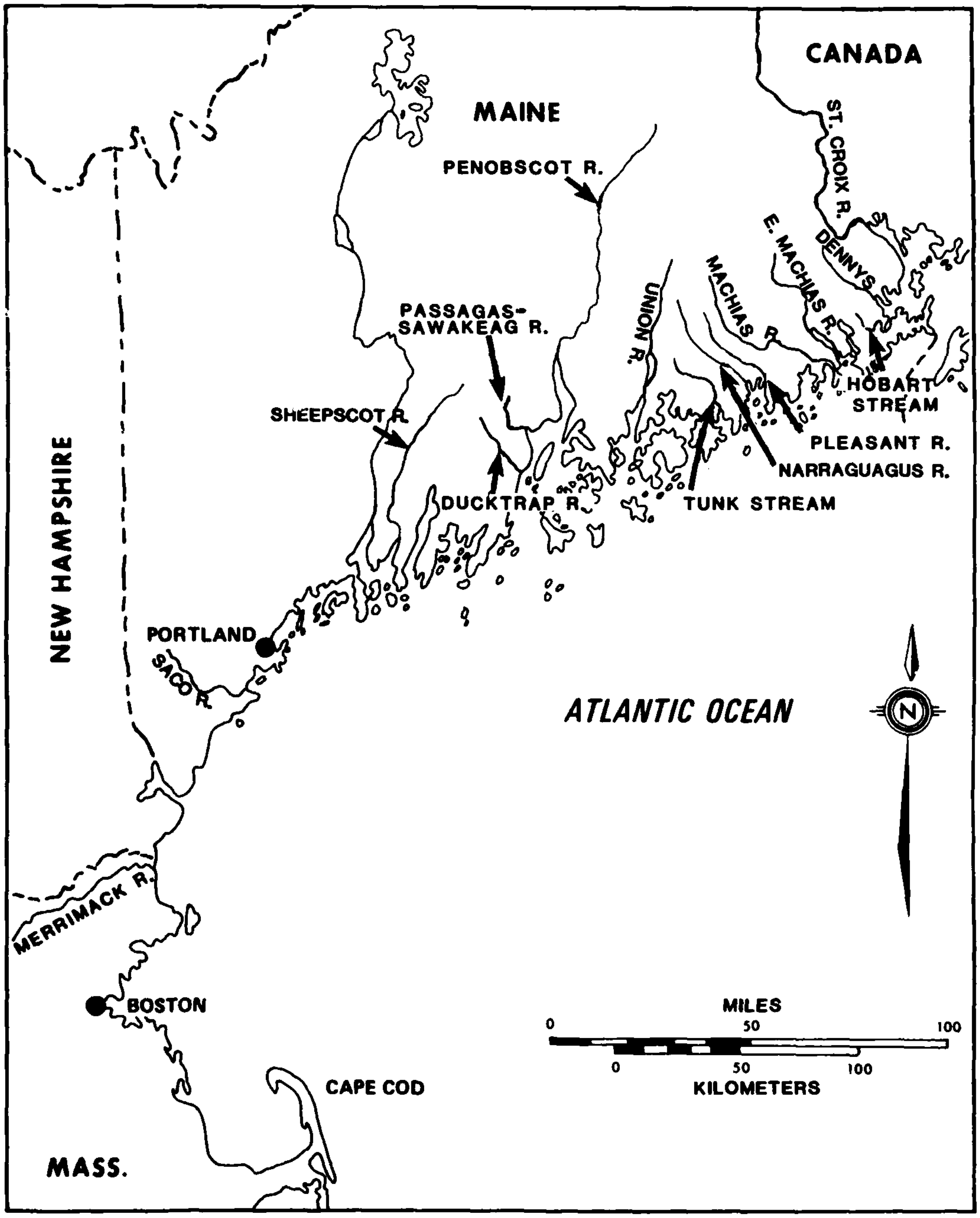

Figure 3. Rivers supporting Atlantic salmon in the North Atlantic Region.

nent is not affected by egg size, but embryo size is larger in larger eggs and the resulting larvae have higher survival (Kazakov 1981). Egg size increases with fecundity and size of females (Pope et al. 1961).

Larvae and Juveniles

After hatching, the eleutheroembryos (alevin or yolk-sac larvae), about 15 mm long, remain buried in the gravel absorbing their yolk sacs for nourishment for about 6 weeks (Bigelow and Schroeder 1953). When the yolk sacs are fully absorbed, the 25-mm fry begin to forage for food in the substrate, and then emerge from the substrate. In a Maine stream, between May 12 and 28 emergence was always at night (Gustafson-Marjanen 1982). In New Brunswick streams, peak emergence and dispersal were between June 12 and 23 (Randall 1982). After emergence, fry disperse and immediately establish territories. The competition for territory may limit the number of fish in the population. The young salmon are also displaced downstream by water flow. By late summer population density of parr is usually less than 50/100 m^2, but may be as much as 370/100 m^2 in New Brunswick (Francis 1980).

Of the eggs deposited, only about 5% result in production of fry. Mortality rates also are high during emergence and dispersion (Ottaway and Clarke 1981). Egg-to-fry survival in Newfoundland streams was influenced by winter temperatures and change in water levels described by Chadwick (1982) in the equation:

$$N_{fry}/N_{eggs} = 68.07 + 1.89X - 0.005Y$$

where X = the lowest mean monthly temperature (°C) and Y = the difference between the November mean discharge and the lowest winter mean monthly discharge (l/sec). Egg-to-parr survival in Cove Brook, Maine, was 10% (Meister 1962).

Chadwick (1982) also related year class strength of smolts to egg deposition in three New Brunswick streams with the equation:

$$\ln Y = 1.29 \ln X - 8.014$$

where X is the number of eggs (thousands) and Y is the number of smolts of that year class.

On reaching a length of about 40 mm during the first summer, young salmon are called parr or fingerlings. These juvenile salmon are found predominately in riffle sections of the stream. Young parr are more numerous in rapidly flowing water during the day and early evening. At night they rest on the bottom in the quieter waters (Gibson 1966). Older parr are residents of the deeper pools in streams. They defend territories and attack other parr entering the defended zone. This practice allocates space and food to ensure adequate growth and reduce predation by other species (Gustafson-Marjanen 1982). Parr frequently move upstream or downstream, perhaps as the result of aggressive interactions, and some parr may migrate to tributaries previously unpopulated with salmon. In New Brunswick streams abundance is usually less than 15/100 m^2 but in a few streams may be as high as 62/100 m^2 (Francis 1980).

In the fall, many male parr become sexually mature (precocious parr), ensuring a mixture of breeding stock (Refstie et al. 1977). Parr remain in the stream until they are 125-150 mm length, which may take up to 2-3 years; they remain in streams until they are 180 mm long and 4-8 years old in the Ungava Bay region of Canada (Schaffer and Elson 1975). Parr that fail to reach the critical length by spring or early summer in any one year do not transform into smolts until the following spring, regardless of subsequent growth (Refstie et al. 1977). If smolts are

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survival of salmon by preventing solar radiation from warming the water above the upper lethal temperature (McCrimmon 1954).

Salinity

Tolerance of Atlantic salmon to sudden changes in salinity differs among its life stages (Parry 1960). Smolts greater than 120 mm can survive an instantaneous change from freshwater (0.1 ppt) to 100% seawater (30 ppt) for 84 hr, and are completely tolerant when introduced into 27 ppt seawater. Parr 7 to 100 mm can tolerate 30 ppt seawater for 10 hr after direct introduction, and survive indefinitely in waters of 22 ppt. Parr 30 - 40 mm are able to survive for only 2.5 hr in 30 ppt seawater but are tolerant of about 18 ppt seawater. Fry 15 - 20 mm perish within 2 hr after sudden introduction into 30 ppt seawater but can tolerate a level of 8 ppt indefinitely. Six-week-old alevins survive for only 0.5 hr in 30 ppt seawater but survive well at salinities near 20 ppt. One-week-old alevins, however, are able to survive up to 9 hr in 100% sea water, even though 3% is optimal. Parry (1960) suggests that the epithelium of these alevins is able to maintain some degree of impermeability, which is lacking in somewhat older fish, and may account for the longer survival of younger fish at high salinities (Figure 7).

Atlantic salmon parr, though adapted for life in freshwater, can readily survive within a wide salinity gradient from 0 to 20 ppt (Shaw et al. 1975). Instantaneous growth rates and food conversion efficiencies of salmon in different salinities were similar.

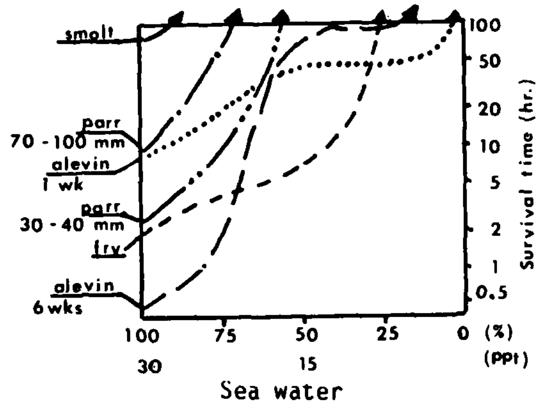


Figure 7. Survival time of different life stages of Atlantic salmon in various seawater concentrations (Parry 1960).

Substrate, Sediment, and Turbidity

The spawning habitat has a particle size composition consisting of 0%-3% fine sand (0.06-0.50 mm); 10%-15% coarse sand (0.5-2.2 mm); 40%-50% pebble (2.2-22 mm); and 40%-60% cobble (22-256 mm) (Peterson 1978). First year fish (0+) prefer a substrate of gravel 1.6-6.4 cm in diameter while parr of age 1+ prefer a boulder and rubble substrate greater than 26 cm in diameter (Symons and Heland 1978). Bottom sedimentation plays an important role in the survival and distribution of juvenile salmon (McCrimmon 1954). Spaces between pebbles and cobble are used as shelter by fry and parr. Deposition of sediments that clog these spaces decrease survival of salmon fry and parr (McCrimmon 1954). Turbidities in excess of 1150 standard units, caused by autumn freshets, did not injure or kill salmon fry and parr. McCrimmon (1954) suggested that turbid water in spring may protect migrating smolts from predation.

lethal pH for embryos is about 3.5 during early cleavage and about 3.1 just before hatching.

Death by low pH is attributed to dysfunction of ionregulation, asphyxiation, and elevation of metal concentrations. Exposure to low pH causes edema between outer gill lamellar cells and other gill tissue, disrupting respiration and excretion. A pH of 5.0 or lower affects eggs by degradation of the enzymes responsible for movement of the embryo within the egg, without which hatching is impossible (Haines 1981). At pH 5.0-5.5 reproduction fails. Alevins subjected to low pH at 7 days and parr at 28 days after hatching had a lower lethal limit of about 4.0 (Daye and Garside 1977; 1980). Rivers in Nova Scotia with a mean pH less than 4.7 have lost salmon runs; between 4.7 and 5.0 runs declined; and above 5.0 runs were unaffected (Watt et al. 1983). Juveniles in these Nova Scotia streams were most numerous at mean annual pH above 5.4, much reduced between 4.7 and 5.0, and absent below 4.7.

Depth and Velocity

The optimum stream habitat for spawning is a gravel tail of a pool with a hydraulic head produced by a riffle or a steeper gradient below the pool. The gravel has an average area of 3.8 m^2.

Water depth over a redd averages 0.4 m in Maine rivers (Beland et al. 1982) and 0.2 m in New Brunswick rivers (Peterson 1978). Water velocity at 12 cm above the substrate averaged 49 cm/sec in Maine, and at 2.5 cm above the substrate, 52 cm/sec in New Brunswick (Elson 1975). The average water depth in a Maine salmon stream was 38 cm (range 17-76 cm) with a water velocity of 53 cm/sec, measured 12 cm above the substrate (Beland et al. 1982).

Atlantic salmon fry less than 60 mm long tend to stay in depths less than 20 cm (Kennedy and Strange 1982). The fry may not be able to compete with older parr in deeper waters because of predation and/or chasing, or they may simply prefer shallower water. Competition for space among fish of different ages may be the critical regulating factor affecting the survival of first-year (0+) fry. In one study (Knight et al. 1981), the preferred fry habitat had a mean depth of 25 cm (range 9-39 cm). The depth of 62 sites where salmon fry were found in New Brunswick streams ranged from 10 to 31 cm (Francis 1980).

Parr, 1+ year and older, seem to prefer waters 10-40 cm deep. Mean depth of preferred areas in New England streams was 29 cm (Knight et al. 1981), and 10-15 cm in Canadian streams (Symons and Heland 1978).

First-year fish (age 0+) prefer water velocities of 50-65 cm/sec (Symons and Heland 1978). Knight et al. (1981) reported that preferred habitat of 0+ fish had a mean velocity of 14 cm/sec (range 1.8-32 cm/sec), whereas 1+ parr were in habitat with a mean velocity of 20 cm/sec (range 14-32). Stream gradients that salmon prefer range from 2 to 12 m/km (Elson 1975).

Resting pools for upstream migrants are important as temporary refuge from swift currents. Large boulders and other stream obstructions provide eddies and slack water in which adult salmon may rest.

Light

At surface illuminations between 0.4 and 160 foot-candles (fc), salmon were photopositive, while at illuminations above 300 fc they were photonegative when the lighted area had an unbroken substrate (Gibson and Keenleyside 1966). With submerged cover in the lighted area, the salmon were photopositive. The amount of shade over a stream indirectly affects the

predaceous fishes; gulls, mergansers, cormorants, herons and kingfishers; and backswimmers and leeches. At sea major predators are pollock, tuna, swordfish, sharks, otters, and seals.

ENVIRONMENTAL REQUIREMENTS

Temperature

Water temperature is the key factor in the delineation of the geographical range of the Atlantic salmon. They require cool temperatures at all stages of their life history. Spawning occurs between 4.4°-10°C. The optimum temperature of egg fertilization and incubation is about 6°C, although development may occur at slower rates at temperatures as low as 0.5°C (Peterson et al. 1977). Temperatures of 7°C are tolerated, whereas temperatures above 12°C increase egg mortality. Temperatures between 8° and 12°C may indirectly increase mortality, due to a higher incidence of fungal infection (Garside 1973; DeCola 1975). Newly hatched Atlantic salmon alevins select the lowest temperatures available. About 250 degree days after hatching the alevins select a temperature of 14°C (Peterson and Metcalfe 1979).

Growth and production of juveniles are optimum at water temperatures of 15°-19°C (DeCola 1970), although they will tolerate temperatures up to 27°C, at which point they move to colder water. Huntsman (1942) stated that salmon could withstand temperatures of 32°C for brief periods. The lethal temperature for juveniles is about 32°C (Garside 1973). Power (1969) suggested that a minimum of 100 days in which the temperature exceeds 6°C is needed for the growing season. Siginevich (1967) reported that growth was optimum at 16.6°C.

Adults grow in ocean temperatures as low as 2°C (DeCola 1975). Mortality can be expected at water temperatures higher than 28°C. Temperatures of 20°-27°C reduce resistance to disease and are therefore indirectly lethal. At water temperatures above 20°C adults are rarely caught by angling.

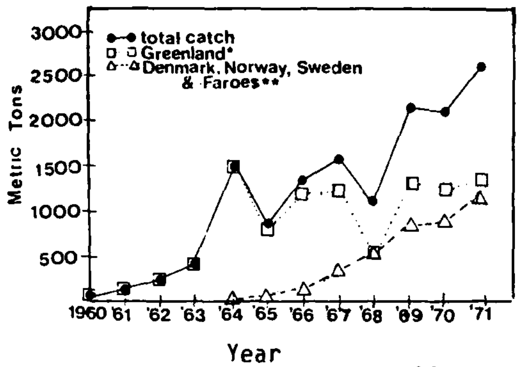
Dissolved Oxygen

For optimum growth and development, dissolved oxygen concentrations should be at or near saturation; good development requires at least 6 mg/l (Elson 1975). Streams with dissolved oxygen concentrations below 5 mg/l are not usually inhabited by salmon. Migrating adult salmon require a minimum of 5 mg/l for exposure less than 6 hr and 6 mg/l for exposure more than 6 hr (DeCola 1970).

The respiration of adult Atlantic salmon is depressed at oxygen concentrations below 4.5-5.0 mg/l (Kazakov and Khalyapina 1981). At concentrations from 1.5-1.7 mg/l, most fish die from a lack of oxygen. Lethal concentrations for juvenile Atlantic salmon are about 1.1 mg/l for age 0+ parr and 2.3 mg/l for age 1+ parr tested at the same water temperatures as the adults. Embryos require even higher oxygen levels of 6-7 mg/l (DeCola 1970). Oxygen consumption differs among fish of different sex, age, and weight. The rate of oxygen consumption in adults decreases with age and body weight.

pH

Fluctuations in pH of water are important in the freshwater environment of the Atlantic salmon (Peterson et al. 1980). Tolerance to low pH varies among different life stages and ages. High mortality of eggs and alevin has been attributed to low pH, which is chacteristic of snowmelt and heavy fall rains. Eggs develop normally at pH 6.6-6.8. A pH of 4.0-5.5 delays or prevents hatching, yet returning these eggs to pH 6.6 induces hatching. The lower



* set gill-net and drift-net
** drift net catch

Figure 6. Greenland and Scandanavian catch of Atlantic salmon from 1960 to 1971 (Dunbar 1973).

trend of increased catches on the high seas (Figure 6), quotas were set (Brewster 1982; Leavitt 1982). The Faroe Island fishery quota was set at 750 metric tons in 1982, and 625 metric tons in 1983. The quota for Greenland was set at 1,250 metric tons for these years. The Convention for the Conservation of Salmon in the North Atlantic Ocean Treaty, approved February 1982, prohibited salmon fishing within 12 mi of another country's coastline, with the exception of West Greenland, where fishing only beyond 40 mi was permitted, and the Faroe Islands where fishing was permitted only beyond 200 mi.

Based on catch by anglers and in traps for hatcheries the total return in Maine in 1982 was 4,685 adult Atlantic salmon, compared to 4,134 in 1981 (U.S. Fish and Wildlife Service 1982). Records are incomplete, however, for some of the smaller rivers. Of the 1982 run, 4,161 were from the Penobscot River. In southern New England in 1982, 46 salmon returned to the Merrimack River, 70 to the Connecticut River (down from the 530 in 1981) and 38 (an estimate of 50) in the Pawcatuck River in Rhode Island, the first time adult Atlantic salmon have returned to this river in nearly 200 years.

As a sport fish, Atlantic salmon are rated as one of the best. They are hard fighters and high jumpers and are considered a prestigous game fish by many anglers. In 1982, Penobscot anglers reported catching 914 salmon (about 1500 were actually caught) during 13,384 angler days on one short section of 115 acres of the river. The average angler fished 38 hr to catch one fish (U.S. Fish and Wildlife Service 1982).

ECOLOGICAL ROLE

Food Habits

Young Atlantic salmon usually remain relatively stationary in the stream and feed on invertebrate drift. Their diet consists chiefly of larvae of mayflies and stoneflies, chironomids, caddisflies and blackflies, aquatic annelids and mollusks. Larger juveniles feed on aquatic insects and terrestrial insects that fall into the water (Scott and Crossman 1973).

In the sea, smolt and larger salmon eat herring, lance, alewives, capelin, smelt, small mackerel, cod, haddock, and crustaceans (Leim and Scott 1966; Scott and Crossman 1973). Salmon eat very little or nothing after returning to freshwater from the sea, but some will attack an angler's lure.

Predation

Salmon are eaten by a variety of predators in freshwater and at sea (Leim and Scott 1966; Scott and Crossman 1973; Harris 1973). Young salmon are eaten by eels, northern pike, brook trout, larger salmon, and other

Table 2. Landings (lb) and values (U.S.$) of commercial catches of Atlantic salmon in Massachusetts and Maine in 1964-1978 (from annual issues of Current Fishery Statistics, NMFS 1983).

	Massachusetts		Maine	
Year	Landings	value	Landings	value
1964	-	-	454	385
1965	8	7	208	161
1966	12	10	292	236
1967	-	-	232	211
1968	-	-	61	61
1969	-	-	18	18
1970	11	10	182	182
1971	-	-	-	-
1972	-	-	100	100
1973	25	25	63	69
1974	35	39	68	84
1975	-	-	269	342
1976	8	14	43	69
1977	-	-	70	100
1978	5	10	474	1115

salmon has been reported for Massachusetts and Maine, where sale of salmon caught with sport gear is permitted (Table 2). Sport catches provide a better measure of the Atlantic salmon fishery (Table 3).

Collapse of the Lake Ontario Atlantic salmon fishery prompted a series of legislative acts in Canada, to control the commercial fisheries. A 1973 ban on drift-net fishing off Newfoundland and on commercial fishing in New Brunswick (both lifted in 1981) was a response to world reductions of Atlantic salmon catch (Hustins 1981).

In the late 1960's and early 1970's, tagged salmon from both sides of the Atlantic were caught in a common area off the west coast of Greenland and off the Faroe Islands (Parrish 1973). Because Atlantic salmon swim close to the surface, they are easy to catch in drift and set gill nets (Dunbar 1973). To reverse the

Table 3. The sport catch of anadromous Atlantic salmon in New England rivers, (Norman R. Dube, Maine Atlantic Salmon Commission, personal communication; Lawrence A. Bandolin, U.S. Fish and Wildlife Service, personal communication).

	Number of fish caught					
River	1978	1979	1980	1981	1982	1983*
Penobscot	360	136	837	725	915	155
Narraguagus	135	58*	119	78	85	89
Machias	105	65+	80	53	59	15
Dennys	75	38+	190	129	40	27
East Machias	60	25	62	85	33	8
Pleasant	16	7	5	23	19	-
Sheepscot	35	5+	30	15	12	10
Union	10	3+	29	32	10	5
Merrimack	1	2	2	2	12	23
Connecticut	0	2	4	13	2	5**
Others***	-	-	20+	-	12	-

* through September 11, 1983
** estimated
*** includes Kennebec, Ducktrap, St. Croix, Androscoggin, and Saco Rivers.

in freshwater and the ocean can be estimated. During upstream migration, the salmon partially absorbs its scales; thus, the number of spawning runs made by an older fish can also be determined (Pratt 1946).

Production (P) of juvenile Atlantic salmon can be estimated from the mean biomass (B) for all year-classes present in a typical Welsh stream (Gee et al. 1978) with the following formula:

$$P = -2.5\ B^{0.91}$$

The exponent actually ranged from 0.73 to 1.24, and the coefficient ranged from -1.91 to -3.05. The higher values appeared in the spring and summer.

According to Egglishaw and Shackley (1977) the size of 0+ salmon in a Scottish river depended on the growing season's length, which is determined by emergence time, degree days above 0°C, and population density (numbers/m^2). The relationship of fork length (FL) to population density (N) and degree days (D) is determined by the following equation:

$$FL = 17.152 - 2.800N + 0.0194D$$

No significant relationship between length of 1+ salmon and their population density could be established. Egglishaw and Shackley determined that the annual production rates for salmon ranged from 5.5 g/m^2 to 12.1 g/m^2 and averaged 8.9 g/m^2. Production in the second year of a particular year class could not be statistically related to production of that year class in its first year of life. Symons (1979) reviewed several studies and noted that smolt production in streams ranged from about 1 to 10 smolts/100 m^2.

COMMERCIAL/SPORT FISHERIES

Atlantic salmon were held in high esteem by the Romans and Gauls. They were an important commercial fish in the British Isles and medieval Europe. They were mentioned in the Magna Carta and were an important source of protein in the American colonies. Settlers found rivers teeming with them. Reports of their capture with pitchforks and their use as fertilizer were documented by Stout (1982). In the late 1800's dams and water pollution destroyed the Atlantic salmon in U.S. waters except for a few streams in Maine. Populations in some Canadian streams were diminished by 1860. At this time Maine had the only remaining profitable commercial Atlantic salmon fishery in the United States. About 70% of the catch was from the Penobscot River, but by 1896, only 40 fish were landed there. Since then, the United States has had no significant commercial catch of salmon (Table 1). This is a biased value since commerical fishing is illegal in the United States. A small catch of

Table 1. Commercial catches of Atlantic salmon in metric tons of the major Atlantic fisheries 1977-1980 (Food and Agricultural Organization 1981).

Country	1977	1978	1979	1980
Canada	2,134	1,320	1,084	2,378
Greenland	2,725	2,163	2,467	2,089
Denmark	1,214	950	1,049	1,133
Ireland	1,184	817	1,528	1,551
U.S.S.R.	344	170	630	966
Scotland	450	472	318	896
Finland	782	568	584	679
Sweden	619	514	570	602
Faroe Is.	40	37	-	533
Iceland	230	291	225	248
N. Ireland	111	150	99	122
Norway	80	87	85	70
France	0	2	3	23
Germany FR	6	8	5	5
U.S.A.	<1	<1	<1	<1

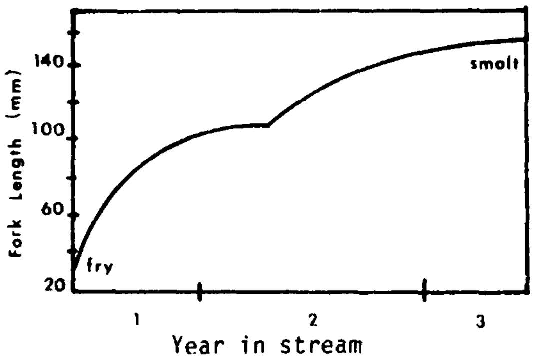


Figure 4. Growth of Atlantic salmon in freshwater (McCrimmon 1954).

Chadwick (1982) warned that the 2.4 eggs/m^2 often cited by management biologists as optimum, may be an "arbitrary" figure and that optimal egg deposition could be considerably higher in productive salmon rivers. Symons (1979) calculated ideal numbers of eggs needed in streams of differing survival and adult escapement, ranging from 23 eggs/m^2 with low escapement and high survival to 591 eggs/m^2 under high escapement and low survival.

Lundqvist (1980) reported that photoperiod also influences growth. Sexually immature male and female Atlantic salmon exposed to a light:dark (LD) ratio of 20:4 grew faster than those exposed to a natural photoperiod (nLD) or LD 6:18. Sexually maturing male parr, however, grew slower in LD 20:4 than did immature fish exposed to the same photoperiod. When exposed to LD 6:18 or nLD, maturing males ripened earlier.

Size is one of the most important factors determining the age at which Atlantic salmon become smolts (Refstie et al. 1977). Fish that become smolts in one year mature and spawn for the first time later than those that smoltify in 2 or 3 years (Ritter 1975). The mean age of the female's first spawning varies over the salmon's range in North America, decreasing from Maine to Ungava (Schaffer and Elson 1975). The mean age of first spawning among individuals is positively correlated with growth rates at sea.

Growth in the sea is faster than in freshwater (Figures 4 and 5). In 1 year at sea a salmon may grow 1-3 kg and in 2 years, 3-7 kg. Average weights of anadromous salmon returning to various streams range from 2 and 9 kg although weights have been recorded up to 38 kg. Commercially caught salmon average 4.5 kg. Adult landlocked salmon average 1-2 kg (Scott and Crossman 1973).

The growth of Atlantic salmon is reflected in scales. When about 30 mm long, the fry begin to grow scales, first along the lateral line at the central and posterior parts of the body. During rapid growth, broad bands form on the scale, similar to growth rings on a tree. These bands are used to determine the age and growth of individuals. Because growth differs in freshwater and the ocean, the time that an individual has spent

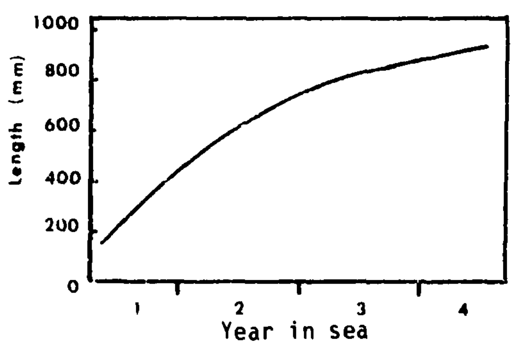


Figure 5. Growth of Atlantic salmon at sea (Allen et al. 1972).

After feeding at sea, most Atlantic salmon return to their natal stream to spawn. Return to the home stream may be aided by detection of olfactory stimuli from the stream that initiate behavioral response mediated by memory of the home stream odor (Stasko et al. 1973). One hypothesis for homeward navigation is that during the downstream migration, smolts release a pheromone, creating an odor trail specific for each population from the home stream to the feeding ground (Fisknes and Doving 1982). Adults may follow this trail to return to their home stream.

Some adults (grilse) return to their home stream after 1 year at sea, weighing 1-3 kg. Other adults (bright salmon) return after 2 or 3 years at sea and weigh 3-9 kg, although much larger salmon have been recorded (Scott and Crossman 1973). Fish returning to Maine rivers usually have spent 2 years at sea (Beland et al. 1982). At sea the returning adults swim at rates of 0.08-0.68 m/sec (Smith et al. 1980).

Salmon congregate in estuaries, bays, and river mouths before migrating upstream. Migration often coincides with freshets or other sustained increases in water flow. Freshets are less important in spring when water is colder and the flow higher than in summer or in autumn (Brawn 1979). Salmon are rheotactic and require a minimum stream velocity of 0.3-0.6 m/sec to continue movement upstream (Weaver 1963). Stasko et al. (1973) reported that the rate of progress upstream against an average flow velocity of 0.5 m/sec (35 km/day) was 4.3 km/day.

Adult salmon do not feed in freshwater. As males mature, their heads become elongate and the lower jaws become enlarged and hooked, forming kypes. The females choose the spawning site. In contrast to Pacific salmon, Atlantic salmon do not die after spawning. Many spent fish (kelts) survive the winter in freshwater and resume feeding. Apparently mortality is high when the kelts enter saltwater. Fish that survive and migrate to oceanic feeding ground may become repeat spawners. Landlocked or permanently freshwater salmon move from the lake where they feed to a tributary stream where they spawn (Havey and Warner 1970).

GROWTH CHARACTERISTICS

Growth of the Atlantic salmon is influenced by both genetic and environmental factors. Embryo size and weight are determined by egg size, which is influenced by the age, size and physiological condition of the female. Egg diameter increases with the age of the fish and the length of time the fish spend in ocean feeding. Egg size also varies in individual females, depending on the position of the eggs in the ovary (Kazakov 1981).

Growth of fry and parr in freshwater is relatively slow (Figure 4). Salmon fry obtain maximum growth in July with little or no growth after September (Randall and Paim 1982). It may take 2-3 years to reach a 125-150 mm fork length in streams in New England, and 4-8 years to reach 180 mm in Ungava Bay (Schaffer and Elson 1975). In productive streams in Maine 1+ parr may reach 150-175 mm, and 2+ parr of 210 mm are occasionally seen.

Normal growth of parr occurs at water temperatures of 15°-19°C (Knight and Greenwood 1981). Population density also affects growth and survival. Growth rates are usually greater where densities are least (Randall 1982). From a study on the Pollett River, New Brunswick, Elson (1975) concluded that average smolt production in an ideal salmon stream should not exceed six smolts/100 m^2. This calculation was based on a spawning intensity of 170 eggs/100 m^2

prevented from seaward migration they again become parr and lose their ability to survive in salt water (Lundqvist and Fridberg 1982).

Smolts and Sea Migrants

The smolt is the next stage in the life history of the Atlantic salmon. In Maine, about 80% of the juveniles spend 2 years in freshwater and 20% spend 3 years. According to Elson (1975) 38% of the parr in the Polett River, New Brunswick survived to smoltification (survival from egg to smolt was 1.1%). Chadwick (1982) reported 3.6% and 3.2% survival from egg to smolt in two Newfoundland streams. Meister (1962) observed survival of 5% from fry to the smolt in Cove Brook, Maine. Symons (1979) analyzed egg-to-smolt survival in the Miramichi River, New Brunswick, and concluded that percentage survival was inversely related to the initial number of eggs deposited. Absolute numbers of smolts produced, of course, was higher in streams receiving heavy egg deposition, up to about 300 eggs/100 m^2, above which density-dependent mortality compensated for increased numbers.

After the parr reach 125 to 150 mm, the parr marks disappear and deposition of guanine in the skin creates a silvery pigmentation. The tail lengthens and becomes more deeply forked. Schooling behavior replaces territorial behavior.

During the spring, rises in water levels due to freshets and water temperature increases +4.5 to +5.5°C induce downstream smolt migration in the Thurso River, Scotland (Allen 1944). Fried et al. (1978) reported that a rise in temperature to 5°C triggered downstream migration in the Penobscot River, Maine. Smolts expressed full migratory behavior at 9°-10°C. Peak movements were at dawn and dusk. In riffles and low-velocity stream sections, smolts orient down stream; but in swift currents, they orient upstream. Migrating smolts passively drift in the main current of the stream away from the shoreline. On reaching the estuary, smolts swim seaward during the flood tide. Impoundments delay or restrict migration. Fried et al. (1978) found that the entire journey from freshwater to seawater took less than 48 hr over a distance of 57 km. Smolt movement in estuaries is dependent on the characteristics of the estuary (Clarke 1981). Stock-specific sun compass orientation and tidal transport are responsible for smolt movement out of an estuary. Movement in deep water is parallel to current direction, while in shallow water sun compass orientation is dominant (Clarke 1981).

Mortality due to freefall over dams and natural falls is likely if the velocity of the fish exceeds 15 m/sec on impact with the water. This velocity is reached by smolts falling a vertical distance of 27 m where discharge is 0.4 m^3/sec (grilse, 18 m, and kelts, 16 m) according to Sweeney and Rutherford (1981). Ruggles (1980) cited that smolts may withstand free fall of up to 90 m.

Sea Life and Homeward Migration

Once in the sea, Atlantic salmon travel to distant feeding grounds (Netboy 1974). Most American and southern European salmon migrate to the Davis Straits between Labrador and Greenland (Figure 2). Salmon from the Baltic Sea and British Isles migrate to the coast of the Faroe Islands. The postsmolts swim within 3 m of the ocean surface at a rate of up to 50 km/day. One possible explanation for their navigating such long distances on target is their ability to detect changes in earth's electromagnetic geoelectric fields caused by the passage of ocean currents through the fields (Stasko et al. 1973).

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15. Supplementary Notes

*U.S. Army Corps of Engineers Report No. TR EL-82-4

16. Abstract (Limit: 200 words)

Species profiles are literature summaries on the taxonomy, morphology, range, life history and environmental requirements of coastal aquatic species. They are intended to assist in environmental impact assessment. Atlantic salmon are a highly prized sport fish and their flesh is gourmet table fare. Once abundant in New England's coastal rivers, they are only now being restored to portions of their original habitat. Populations declined following development of industries along rivers and commercial fisheries in estuaries. Atlantic salmon are anadromous. Spawning, embryo development and growth of young fish occur in freshwater streams and rivers. Juvenile survival is highest in clear, cool (<27°C), well oxygenated (dissolved oxygen $\geq$ 5 mg/l) streams. Following smoltification, a physiological change enabling entry into salt water, fish migrate downstream and then to oceanic feeding grounds near Greenland, where they grow rapidly. Sexually mature fish return to their natal rivers to spawn. Migration into estuaries and lower reaches of rivers begins 7 months before the October-November spawning period. Migrating adults require dissolved oxygen concentrations greater than 6 mg/l for successful upstream movement. Because juveniles migrate through the coastal zone in spring and adults in summer and fall the species is especially vulnerable to the consequences of coastal development.

17. Document Analysis a. Descriptors

Salmon
Fishes
Rivers
Migration

b. Identifiers/Open-Ended Terms

Atlantic salmon
Salmo salar
Temperature requirements
Habitat requirements
Spawning
Life history

c. COSATI Field/Group

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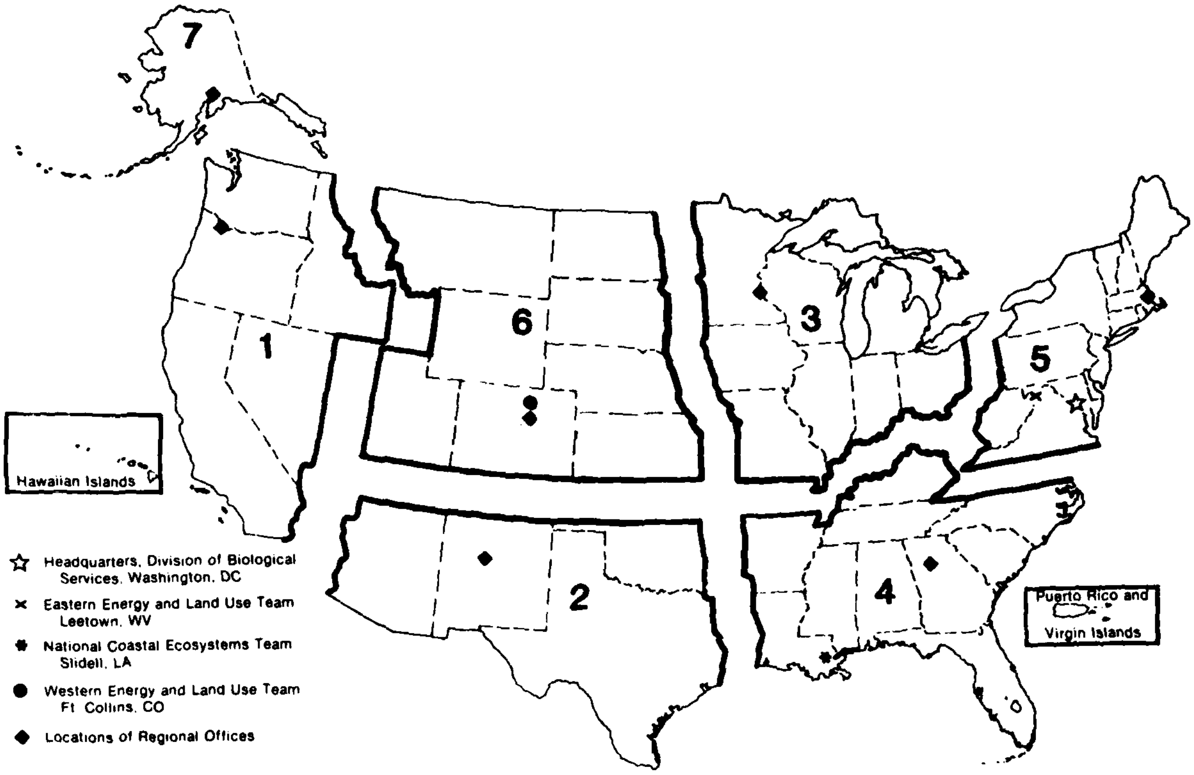

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